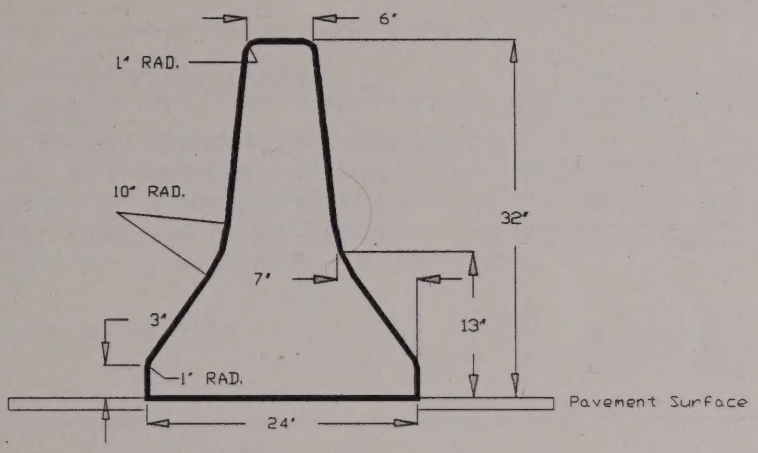
FHWA/NJ-91-001-7630

SUPERPLASTICIZED CONCRETE CURB



Robert R. Santoro
Project Engineer, Research

FINAL REPORT
May, 1991

NEW JERSEY DEPARTMENT OF TRANSPORTATION
Division of Research and Demonstration

NJ
TE
228
S26
1991
c. 1

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/NJ-91-001		

4. Title and Subtitle	5. Report Date
Superplasticized Concrete Curb	May, 1991
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Robert R. Santoro, Project Engineer	91-001-7630

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Bureau of Transportation Structures Research Division of Research and Demonstration New Jersey Department of Transportation 1035 Parkway Avenue, Trenton , NJ 08625	11. Contract or Grant No. NJHPR Study 7630

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Federal Highway Administration Washington, DC	A final report
	14. Sponsoring Agency Code

15. Supplementary Notes

Conducted in cooperation with the USDOT, FHWA

16. Abstract

(See Attached)

17. Key Words	18. Distribution Statement
Portland Cement Concrete, Super water reducers, workability air content, w/c ratio, strength, air-bubble system, durability, constructability	Copies available on request.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	65	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

SUPERPLASTICIZED CONCRETE CURB

ABSTRACT

The ability of three commercially available concrete Super Water Reducers (SWRs) to improve the asbuilt surfaces of New Jersey barrier curb, their effect on basic concrete properties, including workability, air content, compressive strength, the air-void system in the hardened concrete and durability were evaluated. Study test data represents over one hundred days of concrete production consisting of both precast and cast-in-place (C-I-P) SWR concretes.

While the increased workability provided had a positive effect on constructability, particularly on precast elements containing reinforcement steel, C.I.P. asbuilt curb surfaces were only moderately improved.

As expected, study admixtures facilitated reductions in w/c ratio. In the case of three C-I-P trial curb installations, the average compressive strength (6255 psi.) represented a 21 percent increase over the strength level attained by the same mix without a SWR admixture.

Key bubble system parameters were typically inferior -- spacing factors were about twice the desired value of 0.008 inches -- to that commonly considered needed to provide freeze-thaw resistance in conventional, non-SWR concrete. However, based on information in the literature, progressively larger spacing factors can be tolerated for a given mix and conditions provided that w/c ratios are appropriately reduced. Test data indicates the needed relationship between these two key parameters was achieved on study projects.

Trial barrier curb installations continue to exhibit satisfactory durability after three winters exposure to New Jersey conditions.

Recommendations pertaining to specification changes to permit use of SWR admixtures for most concrete items, and follow-up performance monitoring efforts are presented.

NOTICE

This publication is disseminated in the interest of information exchange.

The opinions, findings, and conclusions expressed in the publication are those of the author and not necessarily those of the New Jersey Department of Transportation or the Federal Highway Administration.

This report does not constitute a standard, specification, or regulation.

IMPLEMENTATION STATEMENT

During the course of this research, interim requirements were developed and adopted to govern the use of super-water-reducing admixtures in precast applications. Implementation of study findings will be completed by adopting the recommended specification changes for both precast and cast-in-place concrete presented in report Appendix C.

ACKNOWLEDGMENTS

The writer extends his appreciation for the excellent cooperation provided by Department units, particularly, Region 3 Materials and Construction personnel.

Also, to Mr. Carey Younger, Principal Research Assistant, who assisted in conducting the study and in preparation of report tables and figures.

The valuable review comments on the draft report, provided by Research Bureau Manager, Jack Croteau, and the efforts of Bureau Secretary, Jayne Karney, who typed the report, are also acknowledged.

TABLE OF CONTENTS

	Page
Conclusions	1
Recommendations	5
PART ONE: INTRODUCTION	
1.1 Background	7
1.2 Statement of Problem	8
1.3 Objectives	9
PART TWO: METHOD OF STUDY	
2.1 General	10
2.2 Materials and Test Methods	12
2.3 Special Testing	14
2.4 Monitoring of Trial Installations	15
PART THREE: FINDINGS AND ANALYSIS	
3.1 Concrete Properties	16
3.2 Plastic Concrete	16
3.2.1 Construction Observations	16
3.2.2 Slump and Air Content	21
3.3 Hardened Concrete	24
3.3.1 Compressive Strength	24
3.3.2 Air-Void System	26
3.4 Other Factors Affecting Concrete Performance	32

Page

3.5 Experimental Barrier Curb Installations 34

3.5.1 General 34
3.5.2 Construction Comments 34
3.5.3 Test Data from Trial Installations 35
3.5.4 Performance of Test Sites 40
3.5.5 Costs 40

REFERENCES 42

APPENDICES

APPENDIX A: Method of Test for Determining Properties of the Air-Void System in Hardened Concrete 45

APPENDIX B: Concrete Test Data 50

Table B-1: SWR Concrete Noise Wall Elements (Project NO. 1: Precast) 50

Table B-2: SWR White Concrete Barrier Curb Elements (Project No. 2: Precast) 52

Table B-3: Conventional White Concrete Barrier Curb (Project No. 3: Cast-in-Place) 53

APPENDIX C: Proposed Modifications to NJDOT Standard Specifications (1989) 54

LIST OF FIGURES

Page

1. SWR Concrete Noise Wall Elements (Project No. 1: Precast) ---------- 17

2. SWR White Concrete Barrier Curb Elements (Project No. 2: Precast) ---------- 18

3. Conventional White Concrete Barrier Curb (Project No. 3: Cast-in-Place) ---------- 19

4. Typical Asbuilt Appearance of SWR Concrete Barrier Curb Surfaces (Precast and C-I-P) ---------- 20

5. Plastic Air Content and Primary Bubble System Parameters (Projects 1 and 2: Precast Concrete) ---------- 29

6. Relationship Between Air-Void Spacing Factor and Durability Factor in Concrete Containing High-Range, Water-Reducing Admixture (from Ref. 12) ---------- 31

7. Plastic Air Content and Primary Bubble System Parameters (Project No. 3: Cast-in-Place Barrier Curb Trial Installations) ---------- 39

8. Typical Appearance of SWR Concrete Curb Surfaces after Three Winters' Exposure (Project No. 3: C-I-P) ---------- 41

LIST OF TABLES

Page

1. Mix Designs ---------- 13

2. Slump, Air Content and Key Air Void System Parameters (Projects No. 1 and 2: Precast Noise Wall and Barrier Curb Elements) ---------- 28

3. Mix Data; Experimental SWR White Concrete (Project No. 3: Cast-in-Place Barrier Curb Trial Installations) ---------- 36

4. Slump, Air Content and Key Air Void System Parameters (Project No. 3: Cast-in-Place Barrier Curb Trial Installations) ---------- 38

SUMMARY OF OBSERVATIONS

and

CONCLUSIONS

The principal observations and conclusions from this study of precast and cast-in-place (C-I-P) superplasticized concrete mixtures are as follows:

1. Constructability: Introduction of a SWR admixture increased mix slumps to relatively high levels (up to 9 inches) without causing mix segregation or significant slump loss problems. It should be noted, however, that the potential for rapid slump loss was largely eliminated by introducing the admixture at the construction site and the type items involved in this study (i.e., SWR concrete was typically placed with little or no delay after mixing).

As expected, the increased workability of the admixture modified concrete generally benefitted placement and spreading operations, particularly for those precast elements containing reinforcement steel.

2. Asbuilt Curb Surfaces: Based on the results achieved with the SWR concrete in three C-I-P barrier curb trial installations on project no. 3, as-constructed curb surfaces were only moderately improved. Thus, the hoped for elimination of the surface void problem (described in report section 1.2) was not completely realized.

3. Dosage Rates: Manufacturer recommended dosages -- estimated from a paper mix design -- were considered adequate for the experimental nature and relatively small C-I-P barrier curb test sites constructed on project no. 3. However, for routine usage, the manufacterur's recommended dosage level and admixture compatibility with other mix materials should be confirmed through the Department's mix design verification provisions. That is, trial batches using proposed materials, including all admixtures and mix proportions. This procedure should also reveal any need to adjust the dosage of another admixture(s) to satisfy mix requirements (e.g., air content limits).

4. Uniformity of Slump and Air Content: The mean slump and air content levels for the SWR concrete on both precast projects No.1 and 2 was about the same (7 inches and 6 percent) and conformed closely to specified target values. However, data from these projects revealed a potential for these parameters to be more variable in SWR concretes than conventional mixes. Also, there was a tendency for lower mean air content levels in the hardened SWR concrete. Study data indicates that current, conventional concrete slump tolerances should be increased, at least initially, to two inches and air content target levels and tolerances increased by one-half percent for all SWR concretes.

5. Compressive Strength: The strength of the precast SWR concretes from projects 1 and 2 would easily have satisfied current

Department acceptance provisions. In addition, strength data from project 2 indicated that white SWR mix attained 80 percent of its 28 day strength in 24 hours. Thus, strength gain over this period was markedly accelerated relative to conventional white concretes which require approximately one week to achieve this level.

The strength achieved in the C-I-P SWR white concrete used to construct three experimental barrier curb installations on project 3 was substantially greater (on average, over 1,000 psi) than for the same mix without a SWR admixture. This is primarily attributable to the introduction of a SWR admixture into the standard project mix which produced about a 13 percent average reduction in water content (yet provided for better dispersement of cement particles, thus improved hydration efficiency).

6. Durability of Trial Installations: The three C-I-P barrier curb trial sections constructed with SWR concrete on project no. 3 continue to exhibit satisfactory durability after three winters' exposure. This is despite the fact that the quality of the bubble system measured in hardened concrete specimens representing these trial sites was inferior relative to that commonly accepted as needed for freeze-thaw protection in a conventional concrete. For example, the important spacing factor (L) parameter averaged about twice the normally desired value of 0.008 inches.

While the apparent anomally between durability and air-void system quality is yet to be completely resolved, information in the literature indicates that SWR concretes having progressively lower water-cement ratio have the potential, with an adequate period of

air-drying, to tolerate somewhat higher spacing factors and remain durable. This may be the case for the trial sites in this study since reductions in the amount of mix water resulted in an average water-cement ratio (0.34) and spacing factor (0.017") similar to that reported in the literature as providing satisfactory durability (i.e., an ASTM C666 DF of 90 or greater). Thus, given that all other factors are equal -- a proper mix design, good construction practices and adequate air-drying is provided -- it appears achievement of a relatively low w/c ratio (less than 0.40) can be critical to the durability of SWR concrete, particularly those with an inferior bubble system.

7. Costs: Based on recent (6/90) information, obtained from admixture manufacturers and local producers, SWR admixture costs can vary considerably. However, for a typical concrete mixture and dosage level, it is estimated that the unit price (cubic yards) of SWR concrete can range from $5 to $6 higher than a standard non-SWR concrete.

The estimated cost increase may be offset, at least in part, by the advantages offered by these admixtures. Given that the use of SWR's will be optional, the extent of their usage will be dictated by market forces (i.e., benefits to contractor operations). This may include savings relative to labor and/or time as a result of improved constructability or higher compressive strengths. Experience has shown production at precast plants can be increased when the specified detensioning strength is satisfied in less time than required by conventional mixtures.

RECOMMENDATIONS

1. Future use of SWR Admixtures: Based on the demonstrated ability of superplasticizers to increase concrete strength and improve constructability, it is recommended that the Department's standard specifications be modified to permit the expanded use of these admixtures in applications beyond the present use in precast elements. This permitted use of superplasticizers should not, however, extend to concrete pavement and base courses, bridge approach and transition slabs, or bridge decks. Due to the duration, extent and complexity of finishing operations for these items, they are highly susceptibile to the adverse effects of rapid slump losses sometimes observed by other agancies using superplasticizers. It is recommended that the list of items where superplasticizers are permitted be periodically evaluated in light of continuing developments in the field and modified as warranted. This should be accomplished through a cooperative effort of the Department's Research, Design, Materials and Construction units.

2. Specification Changes: To implement the above recommendations, the Department's standard specifications governing concrete admixtures, mix design and acceptance procedures should be modified as shown in Appendix C.

Basically, these proposed specification revisions contain two major changes. The first and most obvious is a change in the slump

requirements necessary to take advantage of this type admixture. The second is the inclusion of two requirements intended to enhance the freeze-thaw durability of superplasticized mixes (a limitation on maximum water cement ratio and a slightly higher target air content for the plastic concrete).

3. Future Durability Evaluations:

o Trial Installations: The experimental barrier curb sections constructed with SWR concrete on project no. 3 should continue to be monitored for the next 3-5 years. The additional monitoring should permit making a determination as to the general level of durability provided by these SWR concretes under typical New Jersey conditions. Hopefully, any discernible or real performance differences between test sites, each containing a different admixture, will also be revealed.

o Data Base: The Department should continue to compile test data relative to the bubble system in hardened SWR concretes. The latter combined with data from this study could prove useful in assessing the durability potential of New Jersey SWR mixes when criteria -- similar to that commonly used for judging the adequacy of the bubble system in conventional concretes -- becomes available. Development of such criteria is a primary objective of an ongoing national study, (NCHRP D10-32A "Durability Testing of High-Strength Concrete Containing High-Range, Water-Reducing Admixtures") scheduled for completion in 1991.

PART ONE: INTRODUCTION

1.1 BACKGROUND

The use of a relatively new class of concrete admixtures -- often referred to as super water reducers (SWRs), superplasticizers, or high range water reducers -- has become widely publicized in recent years. This class of admixtures has the potential to facilitate construction placement operations by significantly increasing mix workability at a given (or reduced) water content. Despite this and other beneficial effects such as improved compressive strengths (1,2), some agencies remain reluctant to use SWRs. This can generally be attributed to potential problems with mix segregation (3,4), excessive slump (3,5,6,7) and air content loss (8,9), and/or the quality of the air void system in the hardened concrete (9,10,11,12,13).

While not the primary focus of this study, changes in NJDOT beam design criteria resulted in a need for the improved concrete workability and higher compressive strengths that SWR concrete can provide. Accordingly, interim provisions governing the use of SWR admixtures in precast, prestressed elements were developed during this work. In an effort to enhance durability, these provisions included a requirement that a penetrating sealer be applied to portions of a beam (essentially end areas subject to leakage through deck joints) or the entire beam when it will be placed in a marine environment. To date, these provisions have performed satisfactorily, thus they continue to be used by our bridge design unit.

This report describes the results of a study undertaken to provide the NJDOT with information on the effectiveness of SWR's in general and an assessment of their usefulness in resolving problems related to the constructability and durability of barrier curb in particular.

1.2 STATEMENT OF PROBLEM

In recent years, the white concrete barrier curb on Department projects often lacked a continuous, smooth, dense surface upon form removal. Localized irregularities (i.e., varying amounts and sizes of surface voids) typically require extensive manual repair and such areas are highly susceptible to premature deterioration when subjected to New Jersey's relatively severe environment (numerous freeze-thaw cycles and deicer applications annually). As the concrete surface erodes, the resulting voids or pockets facilitate the accumulation of additional water and salt which can contribute to further deterioration. In a few instances, this has resulted in the exposure or dislodgement of the mixture's coarse aggregate.

Obviously, the described deterioration process also contributes to the loss of reflectance and thereby diminishes the effectiveness of the white concrete curbing to serve as a traffic delineator. The latter defeats the primary purpose of specifying white curbing.

Since it was believed the increase in mix workability provided by SWR admixtures had the potential to eliminate, or at least alleviate the described surface problem, several Department engineers became interested in their use. In view of the

preceding, this four-year study was initiated (in 1986) to assess the effect these admixtures have on the behavior and basic properties of typical New Jersey concrete mixtures including constructability, compressive strength, air-content and long-term performance. It was anticipated that study results would also provide a basis for deciding if this class of admixtures should be permitted for other items/applications.

1.3 OBJECTIVES

The primary objectives of this study were:

- Surface Condition - Incorporate several SWRs in trial,cast-in-place (C-I-P) installations to determine if the increased workability afforded a typical NJDOT white concrete mix(es) produces a visually improved asbuilt curb surface.

- Mix Properties - Evaluate the influence SWRs have on curb constructability and mix properties, including slump, plastic air content, compressive strength and the air bubble system in the hardened concrete.

- Durability - Monitor the field performance of barrier curb trial installations constructed with SWR concrete to determine if the admixture modified concrete provides satisfactory durability in New Jersey's relatively severe environment.

PART TWO: METHOD OF STUDY

2.1 GENERAL

To expedite the field work and to obtain realistic information, it was decided that experimental curb installations should be constructed and monitored on a then ongoing Department project(s). Obviously, the success of the latter approach was dependent on identifying project(s) wherein all involved parties -- contractor, concrete supplier, materials and construction personnel, etc. -- would be receptive to any needed adjustments to planned operations and/or schedules to accommodate research requirements. This included additional testing at the concrete plant and construction site, increased mixture sampling and testing rates, etc.

Fortunately, a contractor who was providing precast concrete elements on two Department projects -- one involving temporary barrier curb sections and the other posts and panels for a sound barrier -- requested permission to use an admixture modified mix to enhance placement operations and the achievement of early strengths. The subject contractor also indicated his willingness to participate in this research effort. Given the preceding, the Department granted the request and the SWR concretes used on both projects were included in this evaluation. The latter jobs are referred to herein as projects No. 1 and 2. This precast work provided the opportunity to evaluate both the effect this type admixture has on mix properties and the level of compliance with NJDOT acceptance provisions achieved during more or less routine job production conditions.

The cooperation of key parties on a then ongoing C-I-P barrier curb project was subsequently obtained to satisfy remaining study objectives (i.e., to evaluate the ability of SWR's to resolve the previously described curb constructability/durability problem). This work will be referred to herein as project No. 3.

An initial concern about SWR mixture behavior was excessive or rapid slump loss. To alleviate the potential for the latter, it was decided to reduce the time interval between SWR addition and concrete placement by requiring its introduction at the precast or construction site rather than at the concrete plant. The basic procedure employed at the precast facility or project construction site was to mix the concrete in trucks containing 6 to 10 cubic yards, to a target slump of 2 $\pm$ 1 inches, then adding the SWR admixture at the manufacturer's recommended dosage rate to increase the slump to a maximum of 8 + 1 inch. This slump limit was subject to reduction if mix segregation occurred.

During the planning phase of this research, it was intended to evaluate the durability of admixture modified concretes through standard laboratory (ASTM C666) freeze-thaw testing. The latter was subsequently omitted based on concerns about the ability of such testing to provide realistic information as to the expected field performance of SWR concretes. For example, while SWR concretes may or may not comply with laboratory freeze-thaw criteria, they have been reported (14) to exhibit good field durability in a recent study of some twelve structures in several states. Thus, in this study, durability of SWR concretes will be gauged entirely on the field

performance of experimental barrier curb installations constructed as part of this research effort.

2.2 MATERIALS AND TEST METHODS

The three commercially available SWR admixtures* included in this study satisfied the requirements of current AASHTO M194 (Type F), "Chemical Admixtures for Concrete". The type cements, aggregates, and other admixtures, along with the mix design criteria for the studied projects are presented in Table 1. Materials and mix designs complied with the appropriate provisions (Sections 605, 901.13 and 914) of the NJDOT Standard Specifications for Road and Bridge Construction (1983).

While the materials and mixtures used on study projects were subjected to a variety of quality tests, a summary of the basic test procedures yielding data discussed in subsequent report sections are as follows:

a. Mix slump - AASHTO T119, "Slump of Portland Cement Concrete".

---

*Three types defined by the admixture manufacturer's as: Naphthalene; Sulfonated Sulfonic Polymer; and Modified Naphthalene Lignosulfonate.

TABLE 1: MIX DESIGNS

PROJECT NO.	1	2	3
PROJECT DESCRIPTION	Precast Noise Wall Elements	Precast Barrier Curb Elements	C-I-P Barrier Curb
NJDOT Concrete Class/Designation	B	B-1	B-1
Cement, lbs ASTM C150, Type I	---	705	705
" " , Type II	658	---	---
CA, lbs (note 1) Gravel	1,650	-----	-----
Crushed Stone	-----	1,800	1,800
FA, lbs Natural Sand	1,305	-----	-----
Blends: 70-75% Manufactured plus 25-30% Natural Sand	-----	1,118	1,270
Max. W/C Ratio, lb/lb (gal/bag)	0.487 (5.5)	0.443(5.0)	0.443 (5.0)
A.E.A., oz/bag cement (AASHTO M154)	0.75-1.5	1-2	2-2.5
Retarder, oz/cwt (AASHTO M194)	N/A	2-3	2-3
SWR, oz/cwt (AASHTO M194)	16	10-12	(note 2)
Class Design Strength, psi (AASHTO T22)	3700	3700	3700
Slump, in. (AASHTO T119)	max. 8 + 1	max. 8 + 1	4 $\pm$ 1
Air Content, % (AASHTO T152)	5.5 $\pm$ 1.5	7 $\pm$ 2	7 $\pm$ 2

Notes:

1. Standard size #57 (nominal 1" top size)

2. The SWR dosages used in the experimental barrier curb installations constructed on Project No. 3 ranged from 10-15 oz/cwt.

b. Air content, AASHTO T152, "Air Content of Freshly Mixed Concrete by the Pressure Method".

c. Compressive strength - AASHTO T22, "Compressive Strength of Cylindrical Concrete Specimens".

d. Air content, hardened concrete - modified ASTM C457, "Misroscopic Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete". The procedure used was the same as that employed by Pennsylvania D.O.T. (PTM 623); a copy of which is presented in Appendix A.

It should be noted that when a representative of a SWR manufacturer recommended a slight mix adjustment (e.g., to the ratio of fine to coarse aggregate) to enhance mix/product performance, such modifications were permitted.

2.3 Special Testing

Some of the precast concrete from project 2 as well as portions of the cast-in-place concrete used to construct experimental installations on project 3 was subjected to additional sampling and testing. In those instances, tests and/or specimens were taken both before and after introduction of the involved SWR admixture. Apart

from measuring the increase in slump, this was done in an effort to gauge the influence the admixture might have on other important parameters, such as, air content in the plastic concrete, and/or the air-bubble system in the hardened concrete.

2.4 MONITORING OF TRIAL INSTALLATIONS

The durability of study SWR concretes will be determined from the performance of barrier curb trial installations constructed with materials and mix designs complying with Department requirements and subjected to New Jersey exposure conditions.

The experimental curb sections will be monitored annually for the next several years to determine the existence and severity of any distress condition (e.g., cracking, pitting, scaling, popouts, etc.). In addition, the condition of curb surfaces will be documented with photographs.

PART THREE: FINDINGS AND ANALYSIS

3.1 CONCRETE PROPERTIES

Concrete test data obtained from three study projects -- representing over one hundred days production of precast and C-I-P concrete -- is tabulated in Appendix B (Tables B-1, B-2 and B-3) and plotted here as Figures 1, 2 and 3. The conventional concrete data shown in Figure 3 is basically used as a control in the discussions presented in subsequent report sections.

3.2 PLASTIC CONCRETE

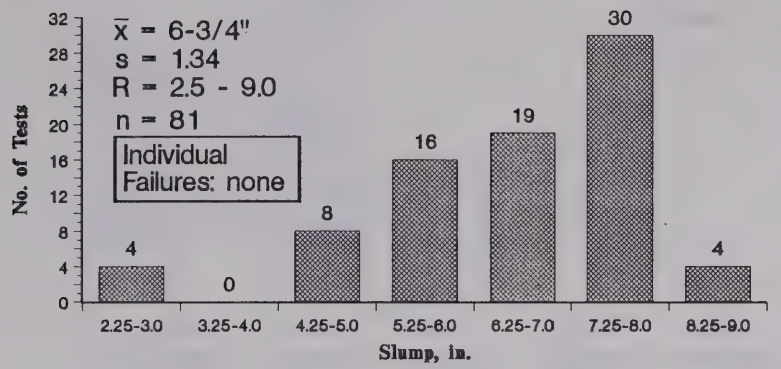
3.2.1 Construction Observations: As expected, observations during the course of this work confirmed that use of an admixture modified concrete facilitated placement operations and thus construction of the barrier curb and noise wall elements studied here. In the case of C-I-P barrier curbing, the quality of as-constructed surfaces were moderately improved. However, the increased mix workability afforded by the SWR admixtures did not completely eliminate the surface void condition described in report section 1.2. The appearance of both precast and C-I-P curb surfaces shortly after construction are shown in Figure 4. Note the even higher quality surface -- uniformly smooth and dense -- of precast elements relative to the C-I-P barrier curb shown in Figure 4. Basically, this is attributed to the orientation of forms during

FIGURE 1: SWR CONCRETE NOISE WALL ELEMENTS

(Project No. 1: Precast)

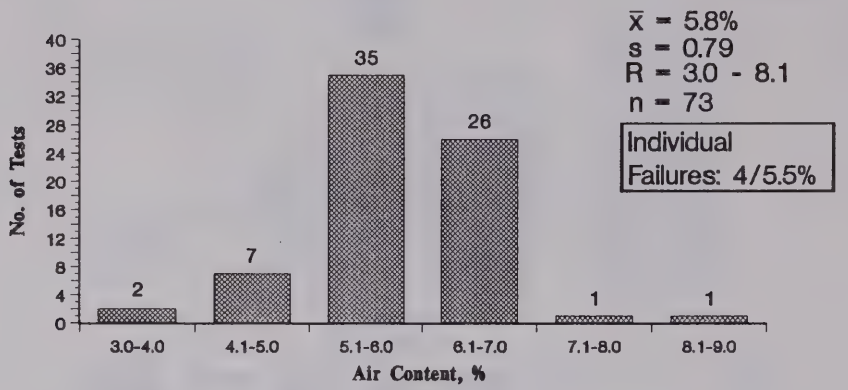
Mixture Slump

(Specification: Maximum 8+1")



Air Content

(Specification: 5.5±1.5%)



Compressive Strength (28 Day)

Typical Target/Aver.:4500 psi
[Min. Acceptance (Indiv. Test): 3300 psi]

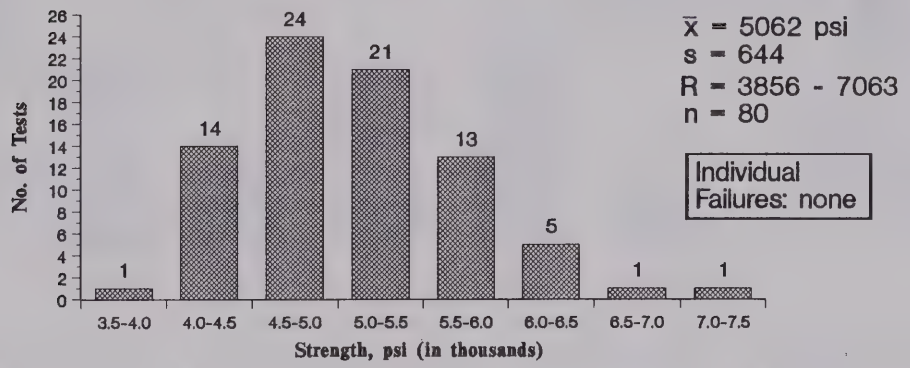
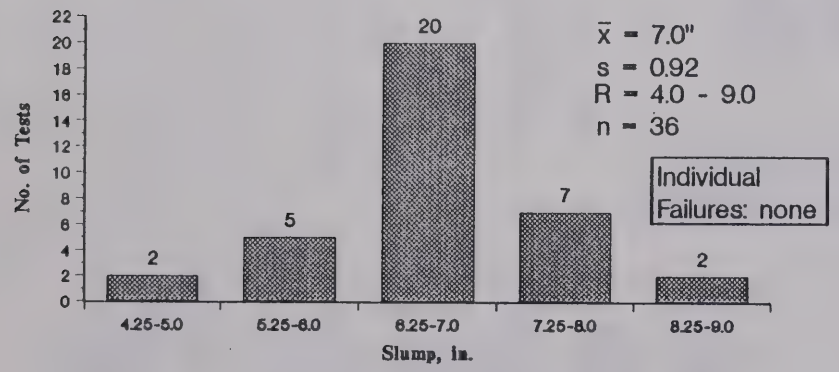


FIGURE 2: SWR WHITE CONCRETE BARRIER CURB ELEMENTS

(Project No. 2: Precast)

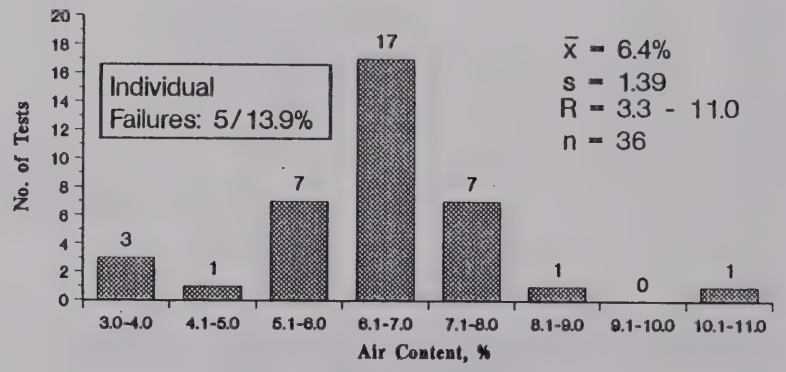
Mixture Slump

(Specification: Maximum 8+1")



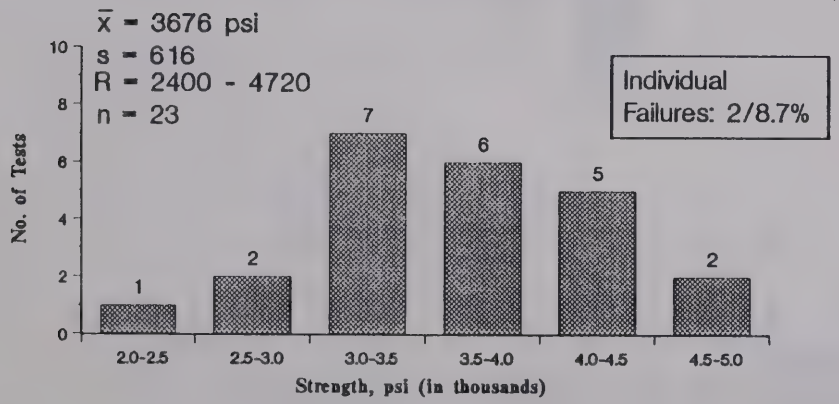
Air Content

(Specification: 7±2%)



Compressive Strength (1 Day)

(Specification: 3000 psi)



Compressive Strength (28 Day)

[Typical Target/Aver.: 4500 psi;
Min. Acceptance (Indiv. Test): 3300 psi]

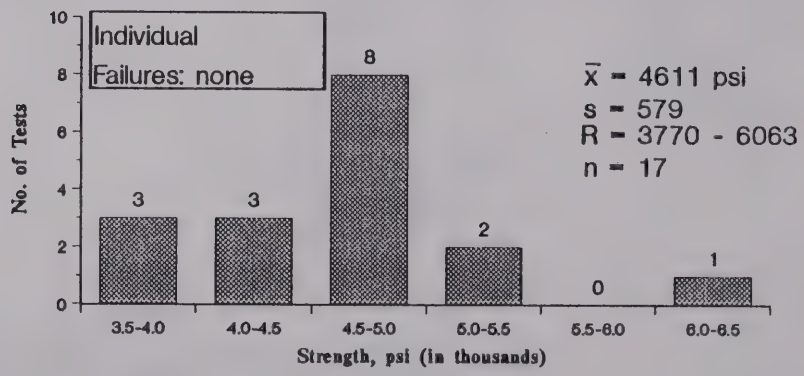
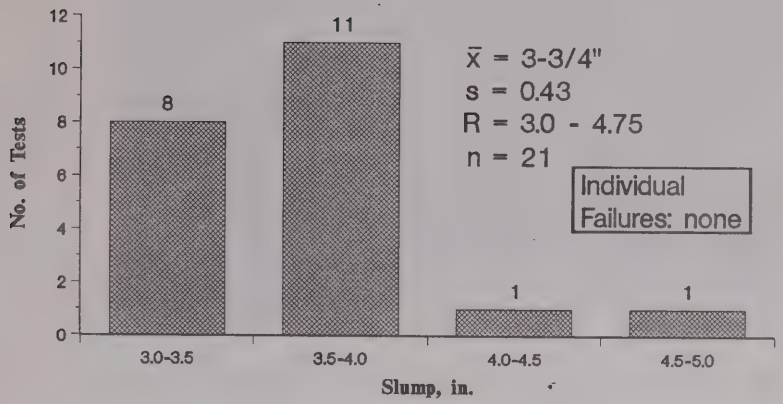


FIGURE 3: CONVENTIONAL WHITE CONCRETE BARRIER CURB

(Project No. 3: Cast-in-Place)

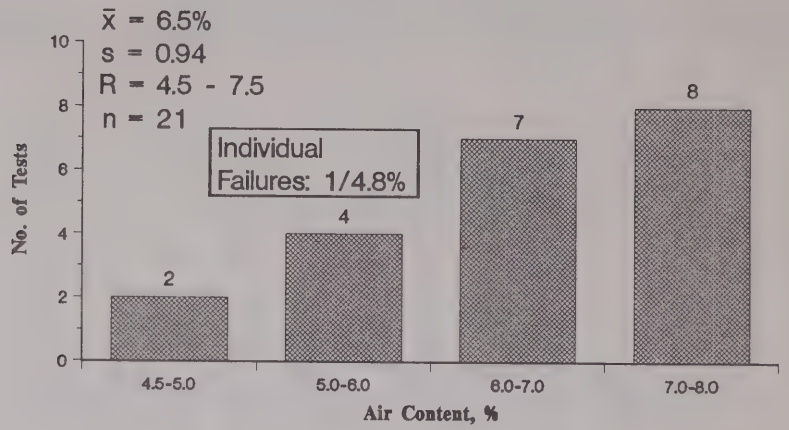
Mixture Slump

(Specification: 4±1")



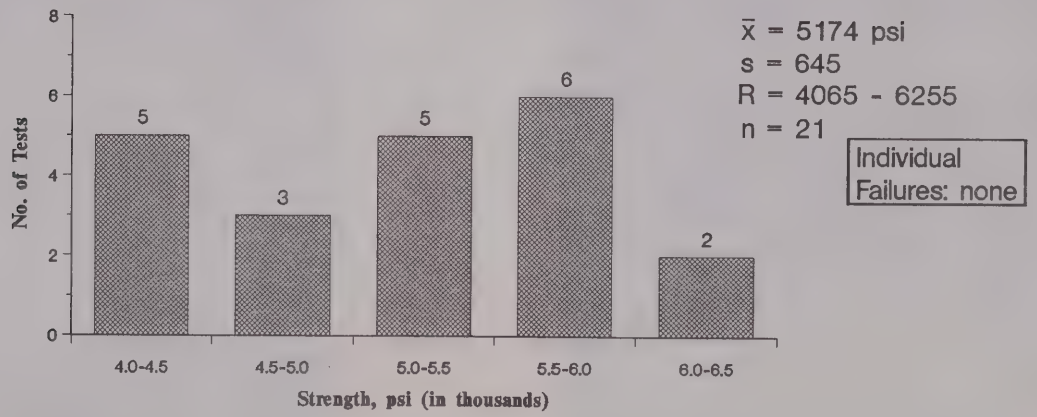
Air Content

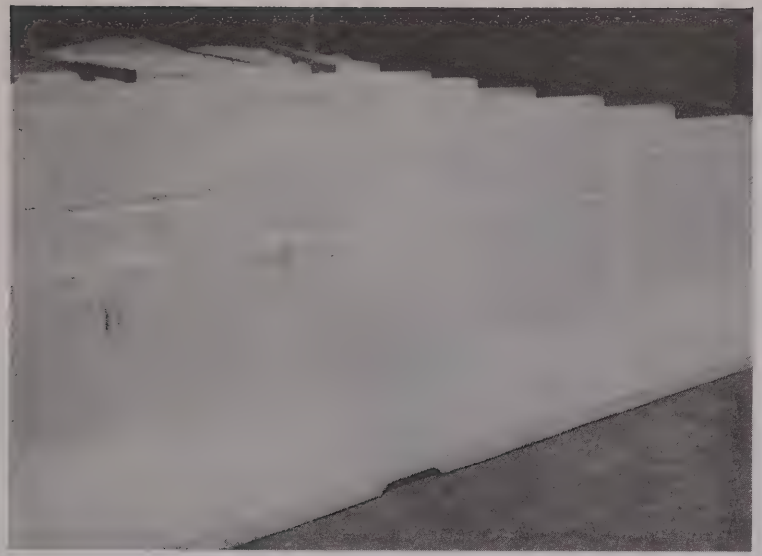
(Specification: 7±2%)



Compressive Strength (28 Day)

[Typical Target/Aver.: 4500 psi
Min. Acceptance (Indiv. Test): 3300 psi]





4a: Precast Concrete, Project No. 2

4b: Cast-in-Place Concrete, Project No. 3 (Trial B, Constructed 10/87)

4c: Cast-in-Place Concrete, Project No.3 (Trial C, Constructed 10/87)

Figure 4: Typical Asbuilt Appearance of SWR Concrete Barrier Curb Surfaces (Precast and C-I-P)

placement (forms are inverted during precasting) rather than the workability or special properties of the SWR mixture.

Apart from enhancing constructability, the overall level of compliance exhibited by study SWR mixtures was favorable, particularly since use of such admixtures is relatively new on Department projects.

Further, the studied admixture modified mixes did not exhibit a severe tendency to segregate or lose slump excessively even at relatively high (8-9 inch) slump levels. The exceptions were one or two batches which initally displayed relatively rapid slump loss (2-3.5 inches in about 10-15 minutes) during C-I-P construction of an experimental barrier curb installation on project no. 3. This condition stabilized after the batch was retempered with an additional dosage of the involved SWR admixture. It is likely that the temperature of this concrete (88 degrees F), which was the highest recorded in this study, contributed to the observed initial slump loss.

A detailed discussion of study SWR mixture compliance with Department acceptance provisions for slump, air-content, and compressive strength, along with an analysis of the air-void system measured in hardened concrete specimens is presented in the following report sections.

3.2.2 Slump And Air Content: As indicated by the summary statistics shown in Figures 1 and 2, the mean slump and air content levels for the SWR concrete used on both precast projects were in

close conformity to specified target values (i.e., an average of about 7 inches and 6 percent on projects 1 and 2, respectively).

Assuming SWR concrete can provide adequate performance and thus, are recommended for routine usage in the future, a brief discussion of the variability associated with the slump and air content parameters seems appropriate. For comparative purposes, Figure 3 presents summary test data obtained from conventional, non-SWR white curb concrete placed on project No. 3. An estimate of variability, based on this sample data, is provided by the standard deviations for mix slump (SDs = 0.4 inches) and air content (SDa = 0.9 percent). Both of the latter are very much in line with previous informal Department evaluations of standard, non-SWR concretes (i.e., standard deviations of about 1/2 inch and 1 percent* for slump and air content, respectively).

Current acceptance requirements for both parameters (slump and air content) are conventionally set at about plus or minus two (2) standard deviations. Thus, the currently specified slump tolerance for all mixes is ± 1 inch while the tolerance for air content is ± 1-1/2 percent for non-white mixes and ± 2.0 percent for white concrete.

As shown in Figures 1 and 2, the variation in slump for the SWR concretes was considerably larger than for the conventional white concrete listed in Figure 3. The SDs values for the SWR concretes on projects No. 1 and No. 2 are 1.3 and 0.9 inches, respectively. This is some two to three times that indicated by the (Project 3) sample

---

* slightly less, about 0.7 percent for non-white concrete.

data from the conventional white concrete (SD_s= 0.4 inches) or the level of variability historically observed. The indicated increase in variation in mix slump is not of great concern when a one-way type specification is employed (e.g., maximum X + Y inches).* However, if a standard two-way specification is used, an increase in slump tolerance of about 1 inch should be considered, at least initially.

In the case of air content, an estimate of the uniformity achieved is provided by the SDa values in Figures 1 and 2. That is, 0.8 percent for the non-white SWR concrete on project No. 1 and 1.4 percent for the SWR white concrete on project No. 2. Based on this and the previous discussion of uniformity limits it appears the currently specified tolerance (± 1.5%) for non-white, conventional mixtures may also be appropriate for non-white SWR concretes. However, it's likely that the increased variability of air content values on project No. 2 (SD_a = 1.4%) contributed to the higher percentage of non-compliant results on that project (i.e., about 14% compared to 5% for the conventional white concrete on project No. 3). Thus, study data suggests the current air content tolerance (± 2%) for white mixtures should be increased, probably to ± 2-1/2 percent for white SWR concretes.

---

* Contractors can, with experience, select a "target" slump sufficiently below the maximum to accommodate the given mix and job conditions.

It is also important to note that most (7 of 9) of the non-compliant air test results for the SWR mixtures on projects 1 and 2 occurred, not unexpectedly, early in the production process and/or were marginal failures. In short, the level of compliance improved considerably as the contractors/producers gained experience with the given admixture modified concrete.

3.3 HARDENED CONCRETE

3.3.1 Compressive Strength: To assess the effect, if any a SWR admixture has on the strength of typical Department mixtures, 28-day compressive strength test results were recorded on both precast projects no. 1 and 2. Additionally, early (24-hour) test results were obtained from project No. 2. Histograms and summary statistics are again presented in Figures 1 and 2.

The data from projects 1 and 2 will be analyzed in terms of how well those SWR concretes would have complied with the Department's currently specified strength requirements for class B concrete. Under the present specification, concrete is accepted by lots, and each is considered acceptable if no more than 10 percent of the concrete contained therein is estimated to fall below the given class design strength (3700 psi for class B).*

---

*Additionally, a minimum strength for an individual test of 3300 psi is specified. The SWR mixes from both projects would also have complied with this provision.

To simplify this analysis, the SWR concretes on projects No. 1 and 2, were each considered as one acceptance lot. Applying conventional statistical procedures to this data indicates that projects No. 1 and 2 have percent defective amounts of only 1.6 and 5.4 percent, respectively. Thus, both would have more than satisfied the Department's current strength requirements.

The 24-hour test data from project No. 2 provides an indication of the effect a SWR has on early strength gain. It can be seen from Figure 2 that after one-day, the white SWR concrete had, on average, attained 80 percent [(3676/4611)100] of its 28-day strength. Conventional concrete normally requires about one week to achieve this percentage. Therefore, for the particular materials and mix design used on project No 2, it is apparent that strength gain, at least in the first 24-hours was markedly accelerated by the inclusion of a SWR admixture. However, the level of improvement, if any, can be expected to vary with project materials, mix designs and job conditions. Indeed, limited data for a SWR mix on another NJDOT project indicated only a slight improvement in early strength gain.

Since study mixes on projects No. 1, 2 and 3 were <u>not</u> identical -- differing in materials and mix designs, including type cement, bag factors, etc. -- <u>direct</u> comparisons of 28 day strength levels are not completely valid. However, it should be mentioned that the mean strength (5174 psi) of the conventional white concrete on project 3 is considered quite unique and perhaps somewhat misleading in that Department white mixes frequently average some 700 psi less (or about 4500 psi).

Finally, the level of variability associated with the strength of SWR mixes on both projects 1 and 2 (approximately 600 psi) is in general accord with the conventional white concrete on project 3 and only slightly higher than historically observed by the Department for class B concrete.

3.3.2 Air Void System: The need for an effective system of entrained air-voids to protect conventional concrete that is subjected to a freeze-thaw environment is well known.

Much of the knowledge on the basic mechanisms that cause physical damage -- expansive forces developed during freezing of internal water -- and the quality of the air-bubble system needed to accommodate and prevent damage from the latter resulted from investigative efforts by Powers, et al., (15, 16, 17) and Backstrom et al. (18), in studies conducted on hardened portland cement paste.

A number of recent studies (9, 10, 11, 12, 13) indicate that the introduction of a SWR often has an adverse effect on the quality of the air-void system relative to that typically required for protection of the paste in conventional concrete.

The discussion presented herein will focus on two key air-void characteristics indicative of overall bubble system quality. They are the bubble spacing factor (L) and the specific surface area of bubbles (α). Recommended (ACI 345) and commonly accepted limiting values for these parameters are L = 0.008 inches (or less) and α = 600 sq. in. (or greater) per cubic inch of air void volume.

Slump and plastic air content measurements along with the primary bubble system parameters obtained from randomly selected specimens from project 2 (and 1 result from project No. 1) are listed in Table 2 and summarized in Figure 5. Bubble system data, both before and after introducing the SWR admixture are presented for completeness. However, the differences between the mean α and L values for these data sets are insufficient to warrant comparative analysis. This may be due to the quantity of mix water added -- prior to introduction of the SWR -- being insufficient to fully activate the air entraining agent and/or the relatively small sample size. Nonetheless, the remainder of this discussion will address the air-void data obtained from the SWR concrete. As shown in Figure 5, air content was measured in both the plactic and hardened state. The results for the hardened SWR concrete are, on average, only about half the initial or plastic air content. Consequently, the mean air content level (3.3%) in the hardened state is relatively low. Further, some 75% (9 of 12) of the SWR specimens exhibit a bubble system that would not generally comply with conventional criteria [i.e., in Table 2, spacing factors (L) are shown ranging from a very acceptable value (0.0068") to as large as 0.0232" with a mean of 0.0147 inches]. The latter is almost twice the desired value.

Studies of SWR concrete durability, typically based on standard laboratory feeeze-thaw tests (ASTM C666) and/or scaling tests (ASTM C672), have reported mixed results. While some (10) indicate questionable or adverse performance, a number of others (9, 11, 12) reported durable concrete was produced, despite an inferior air-bubble system relative to that commonly needed for protection in conventional concrete.

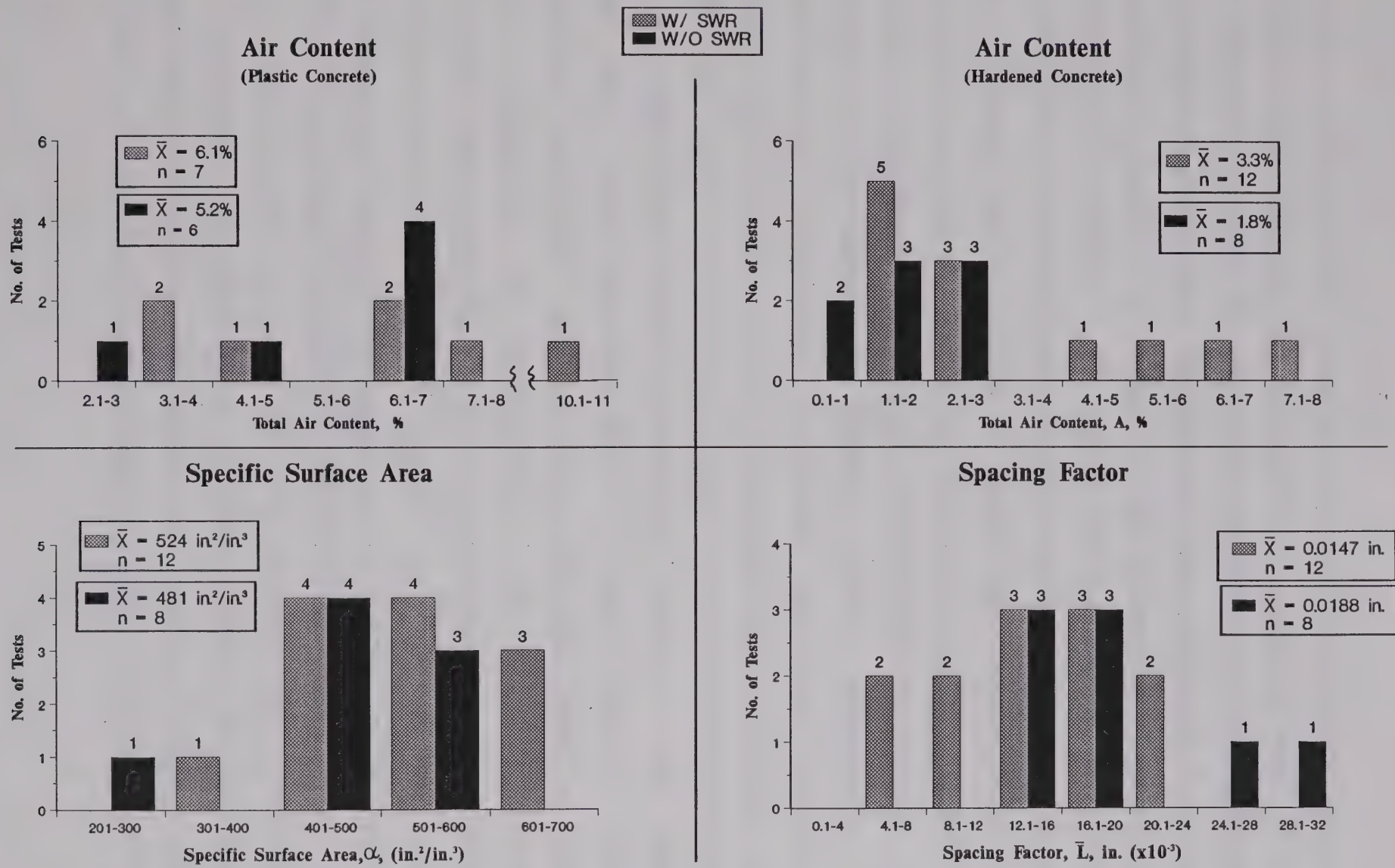
TABLE 2: SLUMP, AIR CONTENT and KEY AIR VOID SYSTEM PARAMETERS
(Projects 1 & 2 : Precast Noise Wall and Barrier Curb Elements)

PROJECT SAMPLE NO.	PLASTIC CONCRETE		HARDENED CONCRETE				
			AIR VOLUME (%)			SPECIFIC	SPACING
	SLUMP (in.)	AIR CONTENT (%)	ENTRAINED Ae	ENTRAPPED At	TOTAL A	SURFACE, α ($in.^2/in.^3$)	FACTOR, $\bar{L}$ (in.)
			SWR CONCRETE				
1-1	7.50	6.4	6.2	0.3	6.5	665	0.0068
2-1	5.00	3.6	1.0	0.5	1.5	475	0.0194
2-2			1.0	0.6	1.6	410	0.0219
2-3	9.00	11.0	4.2	0.4	4.6	617	0.0091
2-4			6.3	0.9	7.2	639	0.0072
2-5	6.75	6.2	2.0	0.6	2.6	523	0.0139
2-6			1.9	0.8	2.7	489	0.0146
2-7	4.00	4.2	0.9	0.6	1.5	400	0.0232
2-8	7.50	7.6	0.9	0.3	1.2	533	0.0190
2-9			4.2	1.3	5.5	538	0.0096
2-10	7.00	3.6	1.9	0.6	2.5	496	0.0149
2-11			1.5	0.4	1.9	505	0.0165
$\bar{X}$	6.75	6.09	2.67	0.61	3.28	524	0.0147
S	1.68	2.66	2.03	0.28	2.11	83	0.0056
n	7	7	12	12	12	12	12
	PRIOR TO INTRODUCING SWR ADMIXTURE						
2-1	3.00	6.0	0.8	1.1	1.9	295	0.0283
2-2			0.8	0.2	1.0	600	0.0182
2-3	3.25	4.9	1.9	0.6	2.5	520	0.0142
2-4	2.25	5.9	1.8	0.5	2.3	515	0.0149
2-5			1.7	0.6	2.3	500	0.0153
2-6	3.50	6.0	0.1	0.5	0.6	436	0.0241
2-7	1.75	2.8	1.1	0.4	1.5	499	0.0185
2-8	3.50	5.8	1.4	0.6	2.0	480	0.0170
$\bar{X}$	3.00	5.23	1.20	0.56	1.76	481	0.0188
S	0.72	1.26	0.62	0.26	0.68	88	0.0049
n	6	6	8	8	8	8	8

* The estimated w/c ratio for these mixes was 0.40, which represents about a 14% average water reduction from the maximum permitted by specification for projects 1 and 2, shown in Table 1.

FIGURE 5: PLASTIC AIR CONTENT AND PRIMARY BUBBLE SYSTEM PARAMETERS

(Projects 1 & 2: Precast Concrete)



In view of the preceding, it is not surprising that concerns exist as to the direct applicability of current, commonly accepted air-void criteria and laboratory freeze-thaw testing to SWR concretes. Resolution of the latter are primary objectives of at least one, ongoing national study (19). Products of the cited study are expected to include an appropriate laboratory test method and/or air-voids criteria specificly for estimating the durability potential of concrete containing a SWR admixture. It is likely that both will be a variant of those currently applied to conventional concrete.

At present however, certain information from a comprehensive Japanese laboratory study (12) concerning the durability of air-entrained, superplasticized concrete bears on the current work. More specifically, they present a family of curves (see Figure 6) which show a general relationship between water cement ratio (w/c ratio), spacing factor (L) and durability factor (DF), the latter based on ASTM C666 freeze-thaw testing. The basic principle being that for a given level of durability (DF), decreases in w/c ratio correspond to increasing L's. In brief, their data shows a strong trend for the spacing factor (L) to become progressively less critical to durability as the amount of mix water is reduced into the relatively low range, achievable by the introduction of a SWR admixture. For example, at a w/c ratio of 0.42 in Figure 6, an L of about 380 um (0.015 inches) or about twice the traditional limiting value provided a very satisfacory DF equal to 95. Importantly, the tabulated data in Table 2 indicates that a similar w/c ratio and L's

were generally achieved in the noise wall and curb elements cast with SWR concrete on projects No. 1 and 2. This suggests that it is unlikely that a durability problem will eventuate, particularly in the case of the noise wall since deicers will not be applied.

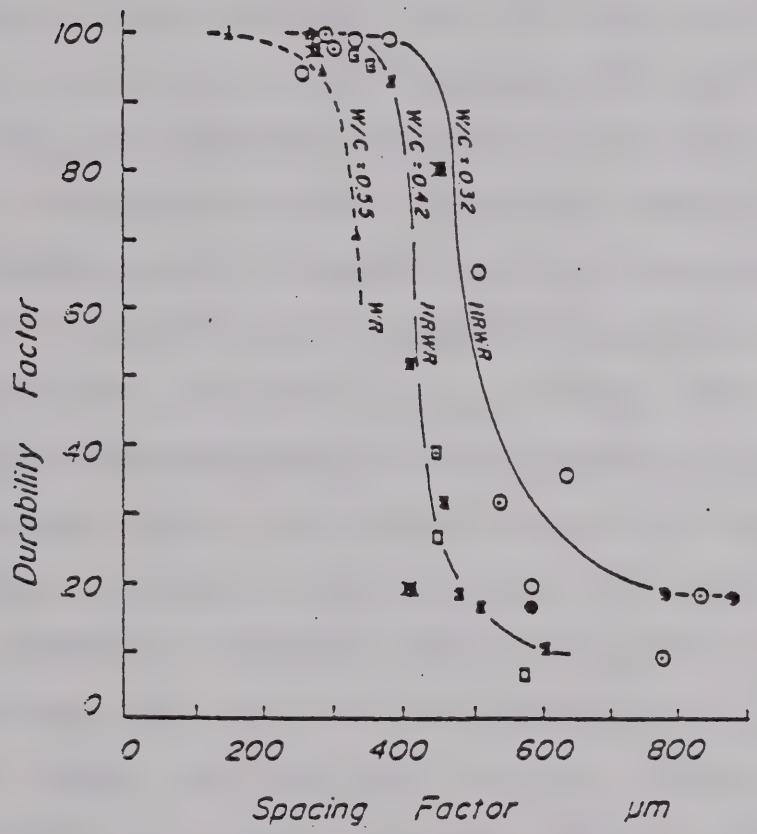


FIGURE 6: Relationship between air-void spacing factor and durability factor in concrete containing high-range water-reducing admixture (from Ref. 12).

3.4 OTHER FACTORS AFFECTING CONCRETE PERFORMANCE

Although not directly addressed in this study, some general factors that influence concrete quality warrant a brief discussion.

Given high quality materials and appropriate mix design, batching and mixing procedures, durability becomes primarily dependent on good construction practices, including minimizing mix water to ensure a relatively low water to cement ratio and sound placement, finishing and curing methods.

In a 1981 in-house Department investigation, (20), deficiencies in the air-void system (bubble size and distribution) of the hardened concrete as well as curing techniques were determined to be the primary causes for the premature deterioration of curb concrete on several Department projects. An additional important factor that contributed to and/or aggravated the observed poor performance was exposure of the concrete to freeze-thaw cycles and de-icers at an early age. The positive impact that a period of "air-drying" -- subsequent to curing and prior to being exposed to an adverse environment -- has on durability has also been reported by others, including Grieb et al., (21) and Sprinkel (1). Data from the latter study shows SWR concretes allowed a period of air-drying generally exhibited a higher level of durability (higher DF's) than moist cured specimens subjected to the same laboratory freeze-thaw test (Modified ASTM C666, procedures A).

The writer believes the beneficial effect of air-drying may take

on added importance when concrete quality is marginal due to moderate deficiencies in other factors (e.g., the air-void system and/or construction practices).

As a result of the earlier cited in-house study, the Department's curb specifications were modified in 1981. This involved three basic changes; an increase in the air-content of plastic concrete (from 6 ± 1-1/2% to 7 ± 2%), more detailed curing procedures, and lastly, to provide a period for "air-drying" prior to the onset of freeze-thaw cycles and thus deicer application, placement of curb concrete is not routinely permitted during the late fall and winter months. These provisions have enhanced concrete quality as we have not experienced a significant curb durability problem since their adoption.

Since SWR concretes often possess a relatively large spacing factor (L's of 0.01 inches or greater), they may be even more susceptible to freeze-thaw damage at an early age than conventional concretes. However, with an adequate period of air-drying, it is doubtful a SWR concrete having a low w/c ratio relative to conventional concrete -- thus a smaller capillary void system -- would have to accommodate as much freezable water. Under these circumstances, it is unlikely that a SWR concrete would need a spacing factor of the same magnitude (0.008 inches) generally required by conventional concrete. However, quantifying the actual size (L) required for different conditions (e.g., varying w/c ratios) is yet to be accomplished and is the subject of at least one, ongoing study (19) cited earlier.

3.5 EXPERIMENTAL BARRIER CURB INSTALLATIONS

3.5.1 General: To supplement the information obtained from projects 1 and 2, three relatively small trial barrier curb installations were constructed using white SWR concrete, by cast-in-place methods on project no. 3. This permitted use of the approved conventional mix design for that project in conjunction with a different manufacturer's SWR admixture in each trial installation. In addition, the completed test sites will be monitored for several years to determine the level of durability provided by SWR concrete subjected to New Jersey conditions.

3.5.2 Construction Comments: A representative of the admixture manufacturer was present during construction of the trial installation containing his product. The dosage of SWR admixture and any minor mix adjustments (e.g., small changes in the amount of fine or coarse aggregate) were as recommended by the involved admixture representative. In an effort to minimize potential slump loss problems, the SWR admixture was added at the construction site in each trial section.

With the exception noted in report section 3.2.1, neither excessive slump-loss or significant mix segregation was observed during placement operations for the three trial sections. Not unexpectedly, workmen felt the high slump SWR concrete facilitated both handling and finishing operations.

As shown earlier in Figure 4, the as-built curb surfaces of the admixture modified concretes were considered moderately improved

relative to the curbing constructed on this project with conventional concrete.

In addition to observing construction operations, standard quality tests were performed on the plastic concrete and specimens were molded for subsequent laboratory testing of the hardened concrete both prior to and after the introduction of the SWR admixture.

3.5.3 Test Data from Trial Installations: As shown in Table 3, mixture slump and air content for the three test installations (A, B and C), averaged 7.0 inches and 5.1 percent, respectively. While both comply with modified slump (max. 8 + 1") and current air content (7 $\pm$ 2%) requirements, certain of the individual results for test sites A and B would not. Clearly, the most desirable slump and air content levels were achieved in the SWR concrete placed in test site C.

In the case of routine future usage, the probability of compliance would be greatly increased by Department provisions which require mix design verification through trial batching.* The latter, prepared with source materials (including all admixtures) and proportions in the proposed mix design must satisfy slump, air content and strength requirements for the given class concrete and construction item.

---

*These provisions were not employed in the project No. 3 research due to the experimental nature and relatively small quantity of SWR concrete involved.

TABLE 3: MIX DATA; EXPERIMENTAL SWR WHITE CONCRETE
(Project No. 3: Cast-in-Place Barrier Curb Trial Installations)

Trial & Date Placed	Location	Temperatures, °F		Slump	SWR Admixture		SWR Slump	Air	Water/Cement Ratio	Estimated Water Reduction (note 2)	Compr. Strength (note 3)
		Air	Concrete	(in)	Type (note 1)	Dosage (oz/cwt)	(in)	(%)	lb/lb(gal/bag)	(%)	(psi)
A (7/87)	Ramp G Sta. 604+20 to 605+80	85	88	3.0	N	10	3.75	3.8	0.33(3.7)	16	6210
		84	86	3.0	N	12	7.0	4.1	0.31(3.5)	21	6320
B (10/87)	Ramp E Sta. 504+30 to 505+04	60	58	2.0	SSP	15	9.75	3.7	0.35(3.9)	10	6380
C (10/87)	SB Collector Sta. 266+02 to 267+62	62	67	4.25	MNL	10	7.5	7.9	0.36(4.1)	8	5925
		63	68	2.0	MNL	12	6.5	6.2	0.35(3.9)	10	6430
Avg.'s	---	---	---	2.75	---	12	7.0	5.1	0.34(3.8)	13	6255

Notes:

1 N = Naphthalene; SSP = Sulfonated Sulfonic Polymer; MNL = Modified Napthalene Lignosulfonate.

2 Based on the difference between the w/c ratios indicated for the SWR mixes and that (0.391) for the non-SWR concrete in the Project 3 mix design.

3 The indicated average (6255 psi) for the SWR mixture represents about a 21% (or 1,000 + psi) increase in the compressive strength (5174 psi) shown in Figure 3 for the same mix without a SWR admixture.

The water to cement ratio and water reduction data of Table 3 shows that use of a SWR admixture produced substantial increases in slump (up to 9+ inches) while the estimated amount of mix water required was reduced from 8 to 21 percent. Consequently, compressive strengths were relatively high, ranging from 5925 to 6430 psi. For test sites A, B and C, the average water reduction was 13 percent with a corresponding strength of 6255 psi. The latter represents a substantial increase (over 1,000 psi) of 21 percent in the average strength level (5174 psi) shown in Figure 3 for this mix without a SWR admixture. As stated in an earlier report Section (3.3.1) the 5174 psi strength level is, in itself, about 700 psi above that typically achieved in Department white concrete mixtures.

Mix slump and air content measurements along with key bubble system data for the hardened concrete is presented in Table 4 and Figure 7. These results are not unlike that presented in report section 3.3.2 for the precast concretes from projects no. 1 and 2.

Accordingly, that basic analysis also applies to the data from the C-I-P trial sections and only a brief recap of the latter will be presented here. As can be seen in Table 4, the total air content of the hardened concrete is again only about 1/2 that measured in the plastic state. Key bubble system parameters (A, α and L) for the hardened SWR concrete shown in Figure 7 are also inferior relative to that needed for freeze-thaw protection in conventional concretes. However, the observed average L (0.0170 inches) is again in line with that reported in the previously cited Japanese study (12) as providing satisfactory durability (a DF of 90) in SWR concrete having a w/c ratio of similar magnitude to the average (0.34) achieved in

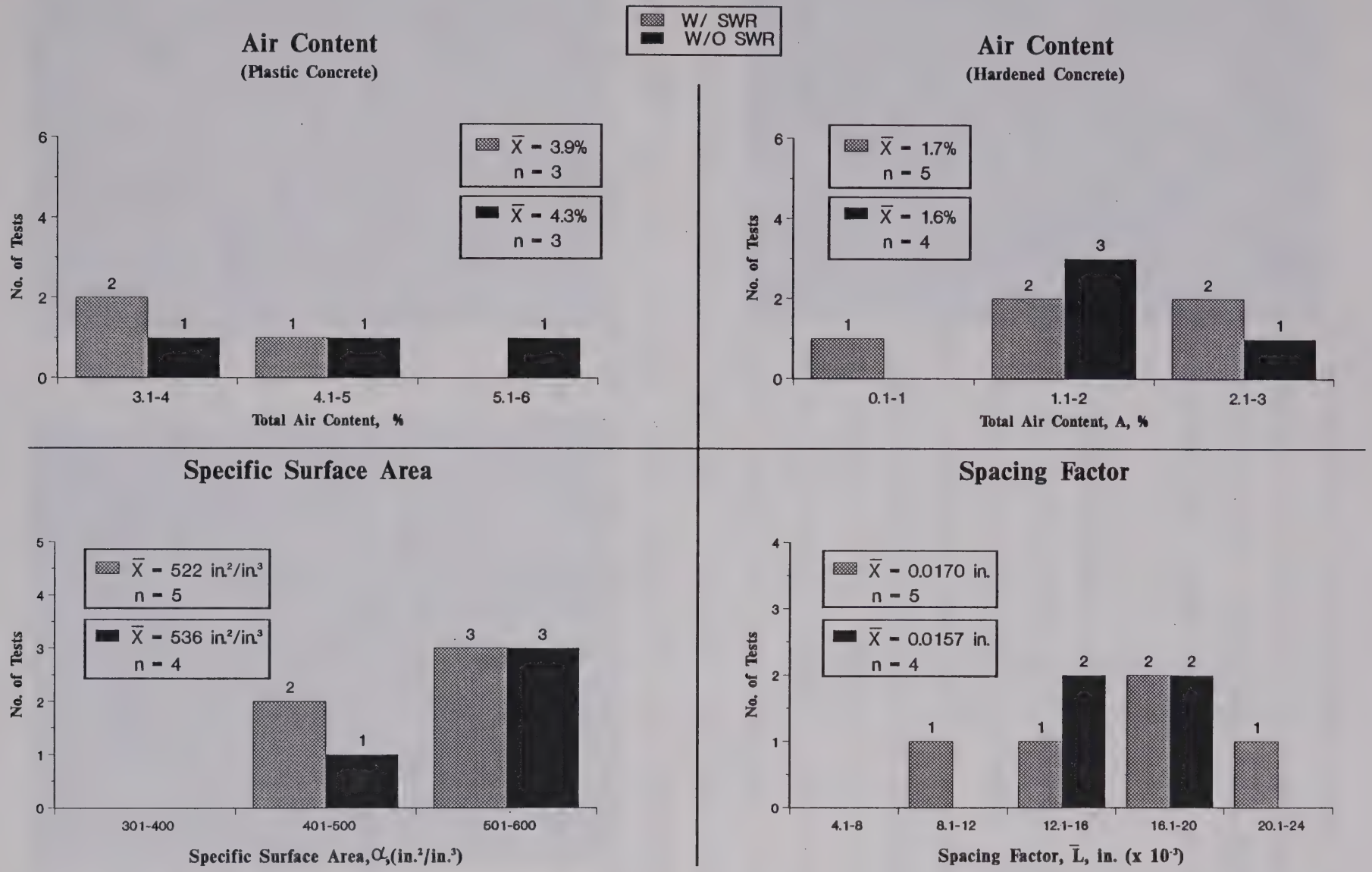
TABLE 4: SLUMP, AIR CONTENT and KEY AIR VOID SYSTEM PARAMETERS
(Project 3: Cast-In-Place Barrier Curb Trial Installations)

TRIAL	PLASTIC CONCRETE *		HARDENED CONCRETE				
			AIR VOLUME (%)			SPECIFIC	SPACING
	SLUMP (in.)	AIR CONTENT (%)	ENTRAINED Ae	ENTRAPPED At	TOTAL A	SURFACE, α ($in.^2/in.^3$)	FACTOR, $\bar{L}$ (in.)
SWR CONCRETE							
A - 1	3.75	3.8	0.9	0.3	1.2	567	0.0167
A - 1	—	—	1.8	0.6	2.4	500	0.0140
A - 2	7.00	4.1	1.0	0.6	1.6	440	0.0190
A - 2	—	—	2.4	0.3	2.7	587	0.0113
B - 1	9.75	3.7	0.6	0.2	0.8	515	0.0238
$\bar{X}$	6.75	3.87	1.34	0.40	1.74	522	0.0170
S	3.00	0.21	0.74	0.19	0.80	58	0.0048
PRIOR TO INTRODUCING SWR ADMIXTURE							
A - 1	3.00	3.7	1.3	0.3	1.6	538	0.0155
A - 2	3.00	4.1	1.3	0.5	1.8	467	0.0170
B - 1	2.00	5.2	1.0	0.1	1.1	587	0.0170
B - 1	—	—	1.7	0.4	2.1	552	0.0134
$\bar{X}$	2.75	4.33	1.33	0.33	1.65	536	0.0157
S	0.58	0.78	0.29	0.17	0.42	50	0.0017

* Averages for the plastic concrete may differ from Table 3 due to varying sample sizes.

FIGURE 7: PLASTIC AIR CONTENT AND PRIMARY BUBBLE SYSTEM PARAMETERS

(Project No. 3: Cast-in-Place Barrier Curb Trial Installations)



the test installations and shown in Table 3. In view of the preceding, the test sites are expected to provide adequate durability, nonetheless they have and will continue to be monitored as described in the next report section for confirmation.

3.5.4 Performance of Test Sites: The three trial curb installations were constructed on project no. 3 with the same basic mix, however, each site (A, B and C) contained a different SWR admixture as indicated in Table 3. These curb installations have been monitored annually (after each winter) since their construction in the summer/fall of 1987. The current condition of test sites A, B and C, after three winters exposure, is shown in Figure 8. While not without some imperfections, the level of durability provided to date is considered satisfactory on the basis of either individual test site performance or when compared to adjacent curb sections constructed with conventional white concrete on this project. It is planned to continue annual monitoring efforts for the next 3-5 years.

3.5.5 Costs: Based on recent (6/90) information provided by several SWR manufacturers and local suppliers, the cost of SWR admixtures can vary considerably. Given the typical dosage level used in this study (about 12 oz/cwt), it is estimated the additional or increased cost of SWR concrete relative to a conventional mix, would range from about $5 to $6 per cubic yard. The estimated cost may be offset, at least in part, by the advantages offered by these admixtures.

8a: Trial A

8b: Trial B

8c: Trial C

Figure 8: Typical Appearance of SWR Concrete Curb Surfaces After 3 Winters' Exposure (Project No. 3: C-I-P Concrete)

REFERENCES

1. Sprinkel, M. M., "Super-Water-Reduced Concrete Pavements and Bridge Deck Overlays", TRR 720, (1979) pp. 19-28.

2. Johnson, C. D., and Gamble, B. R., "Effects of Superplasticizers on Properties of Fresh and Hardened Concrete", TRR 720, (1979) pp. 1-19.

3. Sprinkel, M. M., "Effective Field Use of High-Range, Water-Reduced Concrete", FHWA/VA-82-R24, Virginia Highway and Transportation Research Council (Nov. 1981) 96 pp.

4. Malhotra, V. M., "Performance of Superplasticized Concretes That Have High Water-to-Cement Ratios", TRR 720 (1979) pp. 28-34.

5. Perenchio, W. F., Whiting, D. A., and Kantro, D. L., "Water Reduction, Slump Loss, and Entrained Air-Void Systems as Influenced by Superplasticizers", ACI Special Publication 62 (1979) pp. 137-155.

6. Hester, W. T., "Superplasticizers in Ready Mixed Concrete (A Practical Treatment for Everyday Operations)", NRMCA Publication No. 158 (1979), 23 pp.

7. Whiting, D., "Evaluation of Super-Water Reducers for Highway Applications", FHWA/RD-80/132 (1981) 181 pp.

8. Whiting, D., "Durability of High-Strength Concrete", ACI Special Publication 100 (1987) pp. 169-186.

9. Mielenz, R. C., and Sprouse, J. H., "High-Range Water-Reducing Admixtures: Effect on the Air-Void System in Air-Entrained and Non-Air-Entrained Concrete", ACI Special Publication 62 (1979) pp. 167-192.

10. Mather, B., "Tests of High-Range Water-Reducing Admixtures", American Concrete Institute, Special Publication 62, (1979) pp. 157-166.

11. Okada, E., Hisaka, M., Kazama, Y., and Hattori, K., "Freeze-Thaw Resistance of Superplasticized Concretes", American Concrete Institute, Special Publication 68 (1981) pp. 215-231.

12. Kobayashi, M., Nakakuro, E., Kodama, K., and Negami, S., "Frost Resistance of Superplasticized Concrete", American Concrete Institute, Special Publication 68 (1981) pp. 269-282.

13. Saucier, F., Pigeon, M., and Plante, P., "Air-Void Stability, Part III: Field Tests of Superplasticized Concretes", ACI Materials Journal (Jan./Feb. 1990), pp. 3-11.

14. Whiting, D., and Schmitt, J., "Durability of In-place Concrete Containing High-Range Water-Reducing Admixtures",NCHRP No. 296, Transportation Research Board, (9/87).

15. Powers, T. C., "The Air Requirement of Frost Resistant Concrete", Highway Research Board Proc. Vol. 29 (1949) pp. 184-202.

16. Powers, T. C., "The Mechanism of Frost Action in Concrete", Stanton Walker Lecture No. 3, National Sand and Gravel Association/National Ready Mixed Concrete Association, Silver Spring, Maryland, (1965) 35 pp.

17. Powers, T. C. and Helmuth, R. A., "Theory of Volume Changes in Hardened Portland Cement Paste During Freezing", HRB Proc. Vol. 32, (1953), pp. 285-297.

18. Backstrom, J. E., et al, "Origin, Evaluation, and Effects of the Air Void System in Concrete", Proc. American Concrete Institute, Vol. 55, Part 1, pp. 95-121, Part 2, pp. 261-272, Part 3, pp. 359-376, Part 4, pp. 507-517, (1958).

19. NCHRP D10-32A, "Durability Testing of High-Strength Concrete Containing High-Range, Water-Reducing Admixtures", TRB, National Research Council (not yet published) (3/91).

20. Santoro, R., "Premature Deterioration of White Concrete Curb", Research Report No. 81-008-7777, NJDOT (April 1981) 78 pp.

21. Grieb, W. E., et al, "Resistance of Concrete Surfaces to Scaling by De-Icing Agents", TRB Bulletin 323, (1962), p. 43.

APPENDICES

Page

Appendix A: Method of Test for Determining Properties of the Air-Void System in Hardened Concrete ---------- 45

Appendix B: Concrete Test Data ---------- 50

Table B-1: SWR Concrete Noise Wall Elements (Project No. 1: Precast) ----------50

Table B-2: SWR White Concrete Barrier Curb Elements (Project No. 2: Precast) ---------- 52

Table B-3: Conventional White Concrete Barrier Curb (Project No. 3: Cast-in-Place) ---------- 53

Appendix C: Proposed Modifications to NJDOT Standard Specifications (1989) ---------- 54

APPENDIX A

Method of Test for Determining Properties of the Air-Void System in Hardened Concrete

Materials & Testing Division

Pa. Test Method No. 623
Revised November, 1972
5 Pages

Method of Test for
AIR CONTENT OF HARDENED CONCRETE
BY LINEAR TRAVERSE ANALYSIS

Commonwealth of Pennsylvania
Department of Transportation

1. Scope and Purpose

1.1 This method of test describes the procedure for determining the volumetric percentage of entrained air voids in hardened concrete. In this procedure, polished sections of concrete are examined and measurements are made with a stereoscopic microscope and a traversing stage. This method is a modification of ASTM Designation: C-457, Recommended Practice for the Microscopical Determination of Air-Void Content, Specific Surface, and Spacing Factor of the Air-Void System in Hardened Concrete.

1.2 The geometric characteristics of the air void system, the entrained air content especially, are indicative of the resistance to scaling of moist concrete when subjected to freezing temperatures, particularly, in the presence of the commonly used de-icing chemicals.

2. Definitions

2.1 Air Void-a small space enclosed by cement paste and occupied by air. (NOTE 1) This term does not refer to capillary or other openings of submicroscopical dimensions or to voids within particles of aggregate.

NOTE 1: For special purposes, void systems of satisfactory size distribution and spacing may be produced by the evolution of hydrogen resulting from the chemical reaction of metallic aluminum with cement and water.

2.2 Entrained Air Void-an air void less than one millimeter and greater than 0.005 millimeters in diameter. Entrained air voids are typically spherical or nearly spherical in shape.

2.3 Entrapped Air Void-an air void equal to or greater than one millimeter in its smallest dimension. Entrapped air voids are typically irregular in shape. Entrapped air voids are considered to make no significant contribution to the durability of concrete when subjected to freezing temperature.

3. Apparatus

3.1 The apparatus and materials for sample preparation and for measuring the geometrical characteristics of the air-void system shall meet or exceed the minimum requirements set forth in Sections 4 and 6 of ASTM Designation C-457. The apparatus and materials required for sample preparation consists

of power saws, polishing laps, and various abrasive compounds for grinding and polishing the sawed sections of the concrete. The measuring apparatus is essentially a stereoscopic microscope mounted above a movable stage which has electrical and mechanical accessories that permit counting and measuring portions of the intervals traversed as the stage is moved back and forth under the microscope. See Figure 1.

4. Samples

4.1 When the concrete in a pavement or a structure is to be tested by this method, obtain the sample of hardened concrete in accordance with PTM 606. Cores shall have a diameter of at least four inches.

4.2 When a molded specimen of concrete is to be tested by this method, the entire specimen shall be submitted.

4.3 When unusual circumstances do not permit samples to be obtained in accordance with Sections 4.1 and 4.2, above, samples should be obtained as prescribed by the Petrographer, to ensure that samples suitable for testing will be obtained.

4.4 The samples shall be prepared in reasonable conformity to the procedure described in Section 5 of ASTM Designation C-457. The sample preparation consists essentially of sawing a slab of concrete, usually about 4 x 6 x 1 inches, from the sample submitted; one side of the slab is then ground and polished on laps and mounted horizontally on the traversing stage.

5. Procedure

5.1 Total Traverse Length. The total length of traverse required, which depends on the size of the coarse aggregate, is taken from the following table (ASTM C-457) and the number of traverses necessary to provide the required total length are plotted uniformly along one edge of the polished surface of the slab.

Minimum Length of Traverse

Nominal or Observed Max. Size of Aggregate (in.)	Minimum Length of Traverse (in.)
3	120
1½	100
1	95
3/4	90
½	80

5.2 Measurements-Short Method. Under 100x magnification and oblique illumination, the number of entrained and entrapped air voids intercepted by the traverse are counted, the intercepted intervals of entrapped air voids and the total distance traversed are determined. The relationship between the entrained air content and the number of entrained voids per inch is shown in Figure 2. The entrapped air content (%) is calculated from the number and average chord length of the entrapped air voids.

$$A_E = \bar{l} \times n \times 100$$

where $\bar{l}$ = average chord ℓ intercept
n = voids per inch of traverse

The total air content is the sum of the entrained and entrapped air void contents, expressed as percentages.

NOTE 2: The graph in Figure 2 was obtained by plotting the results of 163 linear traverse analyses (using the Rosiwal or long method of analysis). The best fit for these points was determined to be a second order curve with a correlation coefficient of 0.89. The equation of this curve is:

$$0.0253\ X^2 + 1.6017\ X + 0.1147 = Y$$

5.3 Measurements-Long Method. This is the referee method. Also, it is required when the size distribution of entrained air voids is abnormal, such as occurs when the voids are caused by the evolution of hydrogen in the mortar due to the presence of aluminum. In this method, under 100x magnification and oblique illumination, the intervals intercepted by each entrained and entrapped air void (their chord lengths) are determined, as well as the number of voids of each type and the total distance traversed. The volumetric percentage of each type of air void is a function of its average chord length and number of voids.

$$A = \bar{l} \times n \times 100$$

6. Report. Form TR-459, Air Content of Hardened Concrete by Linear Traverse Analysis.

6.1 Report Voids Per Inch, Total Traverse Length, Entrained Air, Entrapped Air, and Total Air. (NOTE 3).

NOTE 3: This same report form includes additional information obtained at the same time that the entrained air content is determined and is provided to permit an evaluation of the concrete.

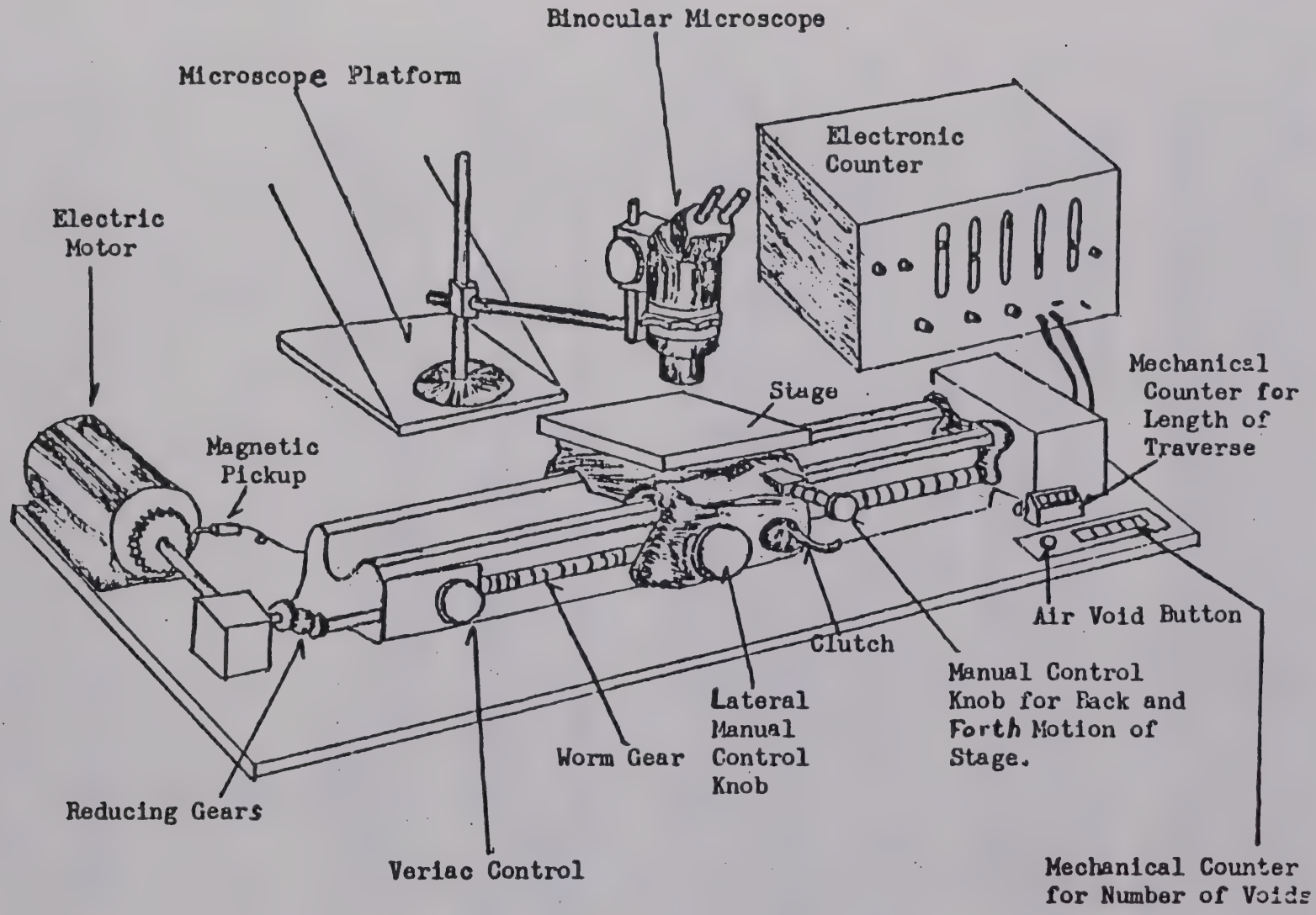

Binocular Microscope
Microscope Platform
Electronic Counter
Electric Motor
Mechanical Counter for Length of Traverse
Stage
Magnetic Pickup
Air Void Button
Clutch
Manual Control Knob for Back and Forth Motion of Stage.
Lateral Manual Control Knob
Worm Gear
Reducing Gears
Veriac Control
Mechanical Counter for Number of Voids

FIGURE 1

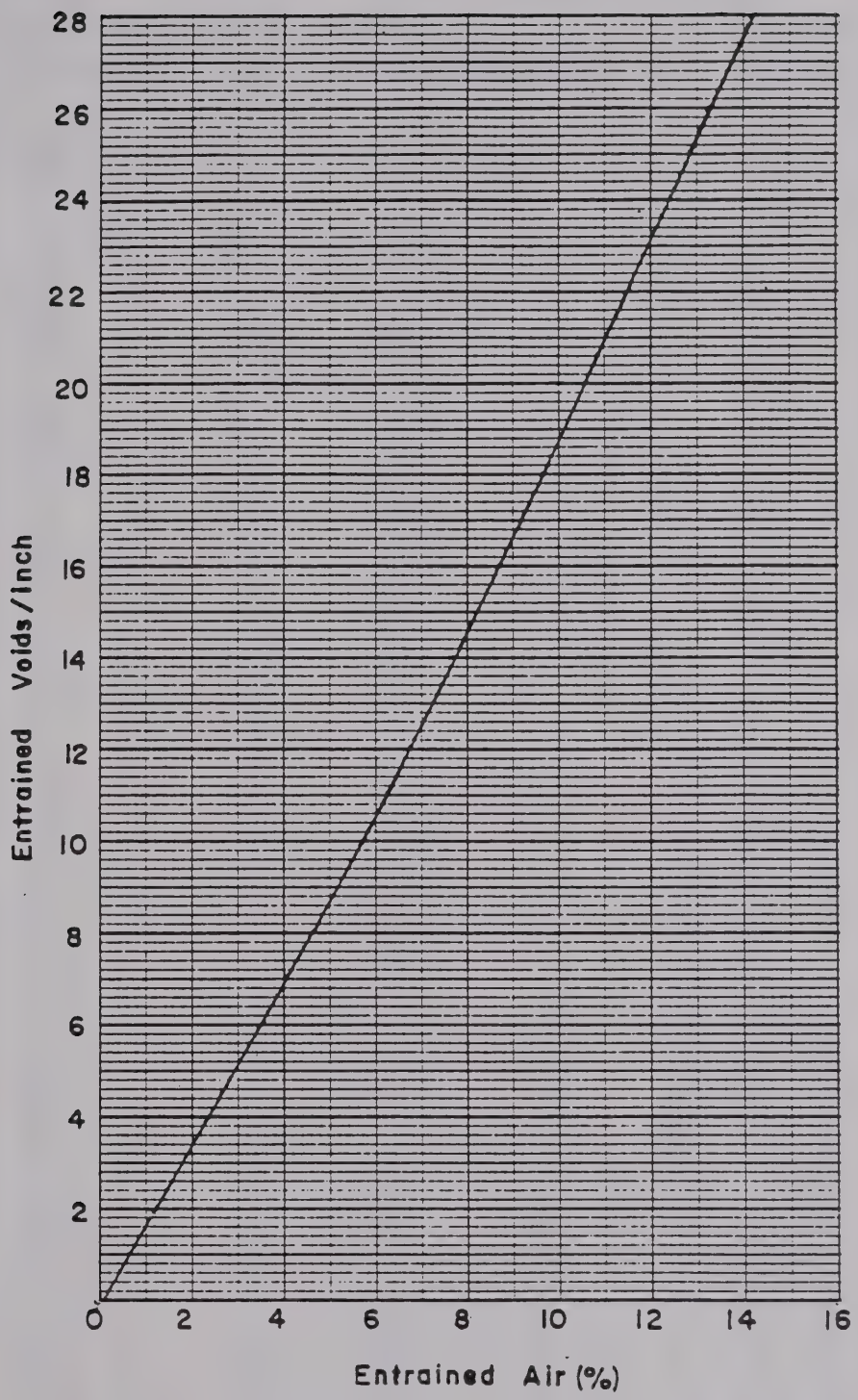

28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
2
4
6
8
10
12
14
16
Entrained Voids/Inch
Entrained Air (%)

FIGURE 2

APPENDIX B: CONCRETE TEST DATA

TABLE B-1: SWR CONCRETE NOISE WALL ELEMENTS
(Project No. 1: Precast)

TEST DAY	TEMPERATURES, °F		MIX SLUMP (in.)	AIR CONTENT (%)	28-DAY COMP. STRENGTH (psi)
	AIR	CONCRETE			
1	84	82	9.00	8.1	6219
2	78	78	9.00	7.6	5506
3	82	76	8.75	4.0	5104
4	80	70	7.50	3.0	5224
5	82	84	7.25	3.8	5423
6	76	83	7.75	6.8	4976
7	–	80	5.00	5.3	4954
8	–	80	8.00	6.2	5141
9	–	80	8.00	6.2	4458
10	–	80	8.00	6.2	4574
11	76	76	8.00	6.6	4569
12	78	80	7.00	6.8	4722
13	82	79	6.00	4.8	----
14	74	79	8.00	6.5	4855
15	77	80	7.75	—	4050
16	74	77	7.50	6.8	4197
17	74	75	6.00	6.8	5042
18	80	80	7.75	5.5	4461
19	74	81	7.75	6.2	5245
20	84	82	8.00	6.1	4716
21	78	80	6.75	6.3	5211
22	73	79	6.50	6.0	4796
23	82	80	7.00	6.4	4680
24	84	79	7.00	5.8	4009
25	82	82	7.50	5.2	4822
26	76	80	8.50	5.7	5694
27	72	78	6.00	6.3	6249
28	80	78	7.00	6.2	5270
29	68	78	7.25	6.0	6095
30	78	78	7.00	6.2	5034
31	79	80	—	6.2	4940
32	80	78	7.75	6.0	5435
33	76	80	7.50	6.0	5024
34	82	80	7.50	5.9	5624
35	81	80	8.00	6.0	4138
36	85	81	7.00	6.1	4173
37	88	80	7.50	6.2	5411
38	85	82	6.50	6.0	4197
39	85	83	6.00	6.0	5046
40	85	82	6.50	5.9	5034
41	80	81	7.50	5.8	4916
42	70	75	5.00	6.1	4433
43	72	72	6.00	6.0	5122

TABLE B-1 (cont'd)

TEST DAY	TEMPERATURES, °F AIR	TEMPERATURES, °F CONCRETE	MIX SLUMP (in.)	AIR CONTENT (%)	28-DAY COMP. STRENGTH (psi)
44	65	72	6.00	6.0	4775
45	75	80	7.50	6.0	4959
46	75	78	7.00	6.0	4663
47	82	74	7.50	5.8	4114
48	78	73	6.00	5.4	5517
49	84	78	7.00	5.8	5635
50	66	72	6.00	5.5	5584
51	65	55	7.00	—	4337
52	70	76	5.00	—	4657
53	67	75	6.00	—	5258
54	63	78	7.50	—	5647
55	70	78	8.00	6.6	4621
56	74	76	7.00	6.2	5187
57	71	78	7.00	6.2	4139
58	72	80	7.50	6.4	5139
59	68	68	6.50	—	4728
60	70	66	5.00	5.4	5223
61	71	78	6.00	5.6	4969
62	70	62	6.00	6.0	4519
63	70	66	7.50	6.6	4071
64	64	68	5.50	6.0	5345
65	60	65	5.00	5.0	5782
66	66	68	6.00	5.2	6514
67	68	66	4.50	5.0	5581
68	67	76	7.00	6.0	5593
69	69	72	6.00	5.8	4999
70	68	70	7.00	5.4	4680
71	50	59	6.00	5.2	4917
72	58	60	6.00	4.9	5447
73	66	61	3.00	5.2	4884
74	50	57	2.50	4.5	5566
75	64	61	3.00	5.2	3856
76	58	60	8.00	4.4	6320
77	64	57	8.00	6.4	5677
78	59	59	7.00	5.8	7063
79	55	58	8.00	—	4100
80	65	56	5.00	—	—
81	50	58	3.00	—	5720
82	44	58	5.00	4.8	6410
Average	72	74	6.75	5.8	5062
Std. Dev.	9	8	1.34	0.79	644
n	78	82	81	73	80
Range	44	29	6.50	5.1	3207
Min	44	55	2.50	3.0	3856
Max	88	84	9.00	8.1	7063

TABLE B-2: SWR WHITE CONCRETE BARRIER CURB ELEMENTS
(Project No. 2: Precast)

TEST DAY	TEMPERATURES,°F		MIX SLUMP (in.)	AIR CONTENT (%)	COMPRESSIVE STRENGTH (psi)	
	AIR	CONCRETE			1-DAY	28-DAY
1	81	79	4.75	3.5	4445	4840
	83	81	9.00	11.0	3690	4015
2	82	71	6.00	5.8	4315	----
	80	70	6.00	5.5	----	5077
3	84	79	8.00	7.7	----	----
	85	80	9.00	6.8	----	----
	86	80	6.75	6.2	----	4560
4	81	81	6.75	6.2	4545	4665
	81	80	4.00	4.2	----	4235
5	82	74	6.00	6.3	3430	----
	84	73	7.00	6.8	----	6063
6	82	82	7.00	6.5	3890	----
	--	--	----	---	----	4400
7	88	82	7.00	7.6	4000	----
	80	73	7.00	7.0	----	4897
8	85	81	7.00	7.4	3000	----
	88	80	7.00	7.0	----	4633
9	88	--	7.50	6.0	3350	----
	89	80	7.00	7.0	----	5390
10	90	83	7.00	6.8	----	3950
	89	79	----	---	----	----
	89	78	7.50	7.6	3780	3855
11	86	82	7.00	6.0	4070	----
	92	81	7.00	6.2	----	4743
12	91	82	7.50	7.0	3750	----
13	88	--	6.50	6.8	2400	----
	93	80	7.50	6.8	----	4730
	88	80	6.50	7.2	----	3770
14	86	82	7.00	6.5	3150	----
15	88	81	7.50	6.6	3250	----
16	76	78	6.00	7.8	3250	----
17	82	72	7.00	7.9	4240	----
18	86	--	6.00	6.5	2600	----
19	86	84	7.00	3.6	4720	----
	86	86	7.25	3.3	3870	----
20	80	79	7.00	5.4	4310	----
	80	80	7.00	6.0	3310	4560
21	82	--	7.00	5.6	3180	----
Average	85	79	7.00	6.4	3676	4611
Std. Dev.	4	4	0.92	1.39	616	579
n	37	33	36	36	23	17
Range	17	16	5.00	7.7	2320	2293
Min	76	70	4.00	3.3	2400	3770
Max	93	86	9.00	11.0	4720	6063

TABLE B-3: CONVENTIONAL WHITE CONCRETE BARRIER CURB
(Project No. 3: Cast-in-Place)

TEST DAY	TEMPERATURES, °F		MIX SLUMP (in.)	AIR CONTENT (%)	28-DAY COMP. STRENGTH (psi)
	AIR	CONCRETE			
1	70	74	4.00	4.5	5840
	85	74	4.00	5.2	4590
2	80	78	3.50	5.0	5370
	80	82	3.50	5.3	5615
3	60	58	3.25	5.5	5225
	66	60	3.50	7.4	4475
4	51	65	3.50	7.1	4585
	58	66	4.00	7.5	4375
5	68	66	4.75	7.0	4065
	72	70	4.50	7.1	4285
6	72	66	3.75	6.2	4470
7	46	--	3.75	7.0	5535
	57	--	3.00	6.4	6055
8	53	--	3.75	7.0	5150
	57	--	3.00	5.3	6255
9	68	70	4.00	7.2	4995
	67	69	4.00	7.4	5560
10	57	63	3.75	7.3	5905
	57	62	3.50	6.9	5870
11	56	63	4.00	6.9	5095
	56	64	4.00	7.1	5345
Average	64	68	3.75	6.5	5174
Std. Dev.	10	6	0.43	0.94	645
n	21	17	21	21	21
Range	39	24	1.75	3.0	2190
Min	46	58	3.00	4.5	4065
Max	85	82	4.75	7.5	6255

* Eleven test days represent a sampling of the total project data (about 1/4 to 1/3).

APPENDIX C: PROPOSED MODIFICATIONS TO NJDOT STANDARD SPECIFICATIONS (1989)

The Department's current standard specifications should be modified to permit the expanded use of super-water-reducing admixtures as follows:

405.07 Handling, Measuring and Batching Materials

- Add to end of third from last paragraph:

  "Such admixture devices shall also be provided with each truck mixer approved for dispensing admixtures at the project or placement site."

905.02 Chemical Admixtures

- Add to the current list of permitted types:

  "Type F - Water-reducing, high range admixtures."

914.01 Composition of Portland Cement Concrete.

- Add the following (as a separate paragraph) after the last paragraph:

  "A water-reducing, high range admixture may be used in accordance with Subsection 914.05 (Tables 914-1 or 914-2 and Table 914-3)."

914.02 Portland Cement Concrete Design, Control and Acceptance Testing Requirements

(b) Proportioning and Verification

o Add after the third paragraph:

"The use of Type F, water-reducing, high range admixtures shall be in accordance with the admixture manufacturer's recommendation for the given mix design and anticipated field conditions, including the admixture dosage rate(s) and the location (plant or placement site) it is introduced into the mixture. The admixture manufacturer's technical representative shall be on the project site for the first full days' production of mix containing a Type F admixture in order to recommend methods and operations based on prevailing climatic and job conditions."

(c) Acceptance Testing Procedures for Slump and Air Entrainment

o Replace the last three sentences of the third paragraph and the entire 4th paragraph with the following:

"If the average of the two test results for either slump or air-entrainment falls below the lower specification limit, a single addition of mix water (or the approved Type F admixture for those mixes containing a water-reducing, high range

admixture) and/or air-entraining agent will be permitted provided that this additional step can be accomplished without exceeding the time or revolution limits specified in Subsection 405.08. When an air-entraining agent is added, it shall be diluted with water prior to addition to the drum.

Following any permitted additions, the drum shall be rotated at the recommended mixing speed for a minimum of 20 revolutions, the original test results are to be disregarded, and a single test for both slump and air-content performed. Further additions of mix water or admixtures will not be permitted. If the measured values for slump and air-content are not within the ranges specified in Subsection 914.05, Tables 914-1 or 914-2, the load of concrete will be rejected and removed from the project."

914.05 Tables

Tables 914-1 and 914-2 Requirements for Roadway and Structural Concrete Items

o Add a note to both tables (914-1 and 914-2) as follows:

"Note - Except for surface and base course, bridge approach and transition slabs, and bridge decks, a Type F-water-reducing, admixture will be permitted in accordance with subsections 905.02

and 914.02 (b and c). When a Type F admixture is used, the Table slump and air content values for the given concrete item shall be modified as follows:

Slump: 6 ± 2 inches.

Air Content: Increase both the target value and the tolerance by 0.5 percent."

Table 914-3 Mix Design Requirements

- Adjacent to the "maximum water-cement ratio" portion of the Table add "(Note 2)".
- Add a note to Table 914-3 as follows:

  "Note 2 - The maximum w/c ratio shall be 0.40 lb/lb (4.5gals/bag) when a Type F water-reducing, high range admixture is used in accordance with Tables 914-1 or 914-2."

NJDOT RESEARCH LIBRARY
3 4310 00012 5560